CRM 87-92 / December 1987

RESEARCH MEMORANDUM

RELATIONS BETWEEN SUSTAINING ENGINEERING, METHODS OF MANAGEMENT, AND SYSTEM QUALITY

Lewis R. Cabe
James M. Jondrow
John E. Keller
Barbara L. Tuxbury

A Division of CNA Hudson Institute

CENTER FOR NAVAL ANALYSES
4401 Ford Avenue • Post Office Box 16268 • Alexandria, Virginia 22302-0268

89 9 8 130

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY 2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for Public Release; Distribution unlimited.
4. PERFORMING ORGANIZATION REPORT NUMBER(S) CRM 87-92	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Center for Naval Analyses 6b. OFFICE SYMBOL (If applicable) CNA	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) 4401 Ford Avenue Alexandria, Virginia 22302-0268	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING ORGANIZATION Office of Naval Research 8b. OFFICE SYMBOL (If applicable) ONR	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER N00014-87-C-0001
8c. ADDRESS (City, State, and ZIP Code) 800 North Quincy Street Arlington, Virginia 22217	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 65154N; PROJECT NO. R0148; TASK NO.; WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
Relations Between Sustaining Engineering, Methods of Management, and System Quality

12. PERSONAL AUTHOR(S)
Lewis R. Cabe, James M. Jondrow, John E. Keller, Barbara L. Tuxbury

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM TO	December 1987	61

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
01	30	
05	01	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Aircraft industry, Aircraft maintenance, Contractors, Engineering, Maintainability, Management, Measure of effectiveness, Quality, Reliability, Safety, Statistical analysis

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This research memorandum determines the relations btween sustaining engineering (SE) usage, methods of management, and system quality. Principal components analysis was used to combine multiple measures of effectiveness into a single measure of aircraft quality and multiple program characteristics into a single measure of high-level management. Levels of SE usage were used with these measures to determine the relations, if any.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED / UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code) / 22c. OFFICE SYMBOL

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted.
All other editions are obsolete.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

CNA CENTER FOR NAVAL ANALYSES

A Division of Hudson Institute 4401 Ford Avenue • Post Office Box 16268 • Alexandria, Virginia 22302-0268 • (703) 824-2000

15 January 1988

MEMORANDUM FOR DISTRIBUTION LIST

Subj: Center for Naval Analyses Research Memorandum 87-92

Encl: (1) CNA Research Memorandum 87-92, "Relations Between Sustaining Engineering, Methods of Management, and System Quality," by John E. Keller et al., Dec 1987

1. This research memorandum (RM) represents the formal final report on a project requested by the Vice Chief of Naval Operations (VCNO). One of the major elements in his tasking was to examine the relationships, if any, between sustaining engineering (SE) usage, methods of management, and measures of effectiveness related to reliability, maintainability, and safety. Another RM in this series estimates relative SE usage among a large sample of Navy and Air Force aircraft. Still another RM in this series examines measures of effectiveness for aircraft reliability, maintainability, and safety. That RM describes how it was found possible, using principal components analysis, to combine multiple measures of effectiveness into a single measure of aircraft "quality."

In order to complete the comparisons requested in the tasking, a measure of management was necessary. The same technique of principal components analysis has been successfully employed to combine multiple program characteristics into a single measure of "management." (These program characteristics describe the type of "management environment" within which a program office works and are not an indication of how well the program office itself is working.)

The three single measures of relative SE usage, "quality," and "management" were then used to seek out relations. This analysis revealed that "quality" and "management" show a significant positive correlation. "Management" and overall relative SE usage show no obvious correlation. While "quality" and overall relative SE usage show no apparent correlation, changes in quality in particular time periods do show a positive correlation with SE investments in related time periods.

2. Enclosure (1) is forwarded as a matter of possible interest.

for William H. [signature]
Christopher Jehn
Vice President
Navy-Marine Corps Planning
and Manpower

Distribution List:
Reverse Page

Subj: Center for Naval Analyses Research Memorandum 87-92

Distribution List:

SNDL

A1	ASSTSECNAV RES	
	Attn:	Ms. Lisa Davis
FF5	NAVSAFECEN	
	Attn:	Dr. M. Borowsky
FF42	NAVPGSCOL	
FF44	NAVWARCOL	
FF67	NAVFITWEPSCOL	
FKA1A	COMNAVAIRSYSCOM	
	Attn:	PMA 231
	Attn:	PMA 234
	Attn:	PMA 240
	Attn:	PMA 241
	Attn:	PMA 257
	Attn:	PMA 265
	Attn:	Air 119 (6 copies)
	Attn:	Air 511
	Attn:	Air 524
	Attn:	Air 530
	Attn:	Air 540
	Attn:	Air 5165
FKM17	FLEMATSUPPO	
	Attn:	Mr. M. Perruchi
	Attn:	Mr. Jere Engelman
FKQ6A	NAVAIRDEVCEN	

OPNAV

OP-09
OP-098
OP-05
OP-05F
OP-50
OP-506
OP-508C1
OP-51
OP-515
OP-73
OP-74
OP-75
OP-81C
OP-814
OP-816

CRM 87-92 / December 1987

RELATIONS BETWEEN SUSTAINING ENGINEERING, METHODS OF MANAGEMENT, AND SYSTEM QUALITY

Lewis R. Cabe
James M. Jondrow
John E. Keller
Barbara L. Tuxbury

Navy-Marine Corps Planning and Manpower Division

A Division of CNA *Hudson Institute*

CENTER FOR NAVAL ANALYSES

4401 Ford Avenue • Post Office Box 16268 • Alexandria, Virginia 22302-0268

ABSTRACT

This research memorandum determines the relations between sustaining engineering (SE) usage, methods of management, and system quality. Principal components analysis was used to combine multiple measures of effectiveness into a single measure of aircraft quality and multiple program characteristics into a single measure of high-level management. Levels of SE usage were used with these measures to determine the relations, if any.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

SUMMARY

One of the major elements in the Vice Chief of Naval Operations (VCNO) tasking for the sustaining engineering (SE) study was to examine the relations, if any, between SE usage, methods of management, and measures of effectiveness related to reliability, maintainability, and safety. Another research memorandum (RM) in this series estimates relative SE usage among a large sample of Navy and Air Force aircraft. Still another early RM in this series examines measures of effectiveness for aircraft reliability, maintainability, and safety. That RM described how it was found possible, using principal components analysis, to combine multiple measures of effectiveness into a single measure of aircraft "quality."

In order to complete the comparisons requested in the tasking, a measure of management is necessary. The same technique of principal components analysis has been employed to combine multiple program characteristics into a single measure of "management." (These program characteristics describe the type of "management environment" within which a program office works and are not an indication of how well the program office itself is working.) The analysis found that the first principal component accounted for a statistically significant percentage of the variation in the program characteristics, thus supporting the idea of an underlying variable, "management."

The three single measures of relative SE usage, "quality," and "management," were then used to seek out relations, if any. This analysis revealed that "quality" and "management" show a significant positive correlation. "Management" (as defined by program characteristics) and overall relative SE usage show no obvious correlation. This was not surprising, since there is no necessary correlation between the management environment created by high-level choices and management of SE at the program office level.

"Quality" and *overall* relative SE usage show no apparent correlation. SE investments in a particular time period and changes in "quality" related to that time period do, however, show a positive correlation--which is consistent with the general belief that SE can improve quality.

INTRODUCTION

In response to perceived weaknesses in the management of sustaining engineering (SE) services, the Vice Chief of Naval Operations (VCNO) formally tasked the Center for Naval Analyses (CNA) with a study of the subject in June 1985. Specifically, the VCNO charged CNA with:

- Defining SE and differentiating it from other forms of weapon system engineering

- Determining how much the Navy spends on SE and what it receives for those expenditures
- Determining how much SE is really needed
- Determining how the Navy might improve its control of SE.

As a result, CNA developed definitions of the phases of weapon system engineering, including SE, that generally have been accepted within the defense industry. The three basic phases are defined as follows.

- *Original Design Engineering*: All engineering effort, including that involved in development, test, and evaluation, leading up to a final approved weapon system design; that is, all engineering effort occurring before completion of the Physical Configuration Audit, when design is frozen for the full-scale production article.
- *Sustaining Engineering*: Engineering effort involved in setting up and improving production processes, ensuring systems integration, advising on and correcting deficiencies discovered during manufacturing and service use, and assisting in other phases of manufacturing, such as quality assurance and configuration control; the engineering required to ensure that current production articles meet explicit or implicit specifications.[1]
- *Systems Engineering*: Engineering effort applied to existing weapon systems intended to enhance performance, reliability, or maintainability significantly beyond current specifications; or engineering involved in the design of later, improved models of a current weapon system.

On April 29, 1986, Admiral Busey (then the VCNO) was briefed on the preliminary results of the CNA study. In the aggregate, it appeared that approximately 17 million man-hours are devoted annually to SE for aircraft and missiles at a cost to the Navy of approximately $1 billion. It was found, however, that accounting and budgeting procedures for SE vary widely in the aerospace industry and that the information available on the specific services and products (i.e., outputs) provided by SE was not, in general, sufficiently detailed, complete, or consistent for managerial or analytic purposes. Because of these shortcomings, the study team decided to focus on system quality rather than output as an indicator of the results of SE efforts. Because the shift came late in this

1. A more detailed list of the 16 specific tasks constituting SE is provided in appendix A.

first phase of the study, the work was incomplete at the time of the April briefing. But what information was available suggested that relatively moderate levels of SE hours invested per aircraft produced did not have an adverse impact on aircraft quality.

These and other findings led Admiral Busey to give CNA a revised and expanded tasking in May 1986. One of the more important elements in this tasking was to analyze the relationship between SE usage, methods of management, and measures of effectiveness related to reliability, maintainability, and safety (i.e., "system quality").

To answer the question of whether SE usage, management, and system quality are related, the issues of measuring SE usage, system quality, and management had to be addressed.

ANALYSIS

Measuring Sustaining Engineering Usage

Data on actual sustaining engineering (SE) hours used (or estimated to be used at completion) were available, by annual buys, for nine different aircraft during the period 1970 to 1986. SE hours were adjusted for the influence of a number of determinants: annual production quantities, total cumulative production (reflecting a kind of "learning curve" effect), model changes (which interrupt the "learning curve"), size (with airframe weight serving as a proxy), aircraft manufacturing complexity (with physical density serving as a proxy), aircraft design complexity (with maximum mach number serving as a proxy), and speed of adjustment to changes in annual production quantities.[1]

Based on these determinants, regression analysis was used to estimate a "target" level of SE hours toward which actual SE hours appeared to be adjusting. To create a relative measure of SE usage for a given aircraft, total actual SE hours over the aircraft's career were divided by total "target" SE hours over the aircraft's career. (See table 1.)

A value below 1 means that SE hours expended for this aircraft were, on average, below its estimated target; a value above 1 means that SE hours expended were, on average, above the estimated target.

1. The adjustment of SE for all these factors was made using regression analysis, which estimates a conditional average level of SE (conditional on quantities, cumulative production, etc.) based on industry-wide practice.

TABLE 1

RELATIVE SE USAGE[a]

Aircraft	Actual SE hours divided by target SE hours
F-5E	0.83
F-14A	1.04
F-15A/B + C/D	1.04
F-16A/B + C/D	1.06
F-18A/B + C/D	1.10
A-6E	0.82
P-3C	1.06
E-2C	1.23
E-3	1.00

a. A complete description of this work and the underlying data can be found in a forthcoming CRM in this series. See appendix B.

Measuring "System Quality"[1]

As a start in measuring quality, data were compiled on a wide variety of individual indicators of aircraft reliability, maintainability, and safety. These data included measures of maintenance effort, failure rates, and mishap rates. Each of these variables can be regarded as a directly measurable, but incomplete, indicator. Consequently, each measure offers only a partial insight into some overall variable, which can be characterized as "system quality."[2] Quality, it is surmised, is the latent, unobservable variable that finds expression in the values

1. For a more complete description of this work see CRM 87-89, *Measures of Aircraft Reliability, Maintainability, and Safety: Do They Measure "System Quality"?* Jun 1987.
2. It should be noted that because the study focused on the use of SE by prime contractors, data for all the measures of effectiveness (except acceptance testing histories) related to only those parts of the aircraft, or its mode of operation, for which the prime contractor and his SE input are responsible. Thus, maintenance effort or failures due to GFE engines or major avionics systems would not be included, nor would mishaps due to such factors as pilot error, weather, or engine malfunctions. Essentially, the search for a way to measure quality was restricted to the aircraft as a flying machine, *sans* engines, and not as a complete weapon system.

observed for each of the specific variables noted above.[1] To measure quality requires a "distillation" of the observables to try to get at the underlying variable or variables that generated them.[2]

Principal components analysis was the multivariate statistical technique selected for this distillation process. Conceptually, the technique is quite straightforward. A weighted average score is computed for each unit of observation (each type of aircraft in this case), using the aircraft's performance on each of several partial measures of quality (mean flight hours between failure (MFHBF), for example). The weights given to each measure (or variable) are not arbitrarily assigned or chosen a priori by the analyst, but are determined by a well-accepted statistical technique that does so in a way that minimizes the unexplained variance in the entire data set. The first principal component captures the largest possible percentage of the total variance. The remaining principal components are chosen to best account for what variance remains unexplained by the first principal component.

In the case of measures of aircraft reliability, maintainability, and safety, the first principal component accounted for 85 percent of the variance. The statistical significance of an R^2 of 85 percent was checked, using a numerically generated sampling distribution of R^2 values, under the null hypothesis that the underlying variables are uncorrelated. The observed R^2 of 85 percent was highly significant because it lies 7-1/2 standard deviations above the mean of the null-hypothesis sampling distribution.

Because the first principal component scores (interpreted as "quality") of each of the six fighter/attack aircraft used in the base case analysis have no natural units (they are measuring an unobservable), units can be chosen for ease of interpretation. Table 2 presents the

---

1. The term "quality" as used here is limited to airframe reliability, maintainability, and safety--characteristics believed to be affected by SE investments. Quality in this case does not relate to the aircraft's capabilities for performing its intended missions; nor does it refer to the absence or presence of manufacturing defects and sloppy workmanship. Detecting and preventing the latter is primarily the work of quality assurance teams (which, as noted earlier, sometimes do require SE inputs).

2. Attempting to distill the unobservable overall characteristic "intelligence" from a host of measurable variables such as verbal, quantitative, and analytical skills is analogous to what has been done here with respect to aircraft quality. In fact, one of the chief motivators for the development of principal components analysis and related techniques was the intelligence measurement problem.

scores restated into "IQ-type" units; i.e., rescaled to have a mean equal to 100 and a standard deviation equal to 10.[1]

TABLE 2

RESULTS OF THE PRINCIPAL COMPONENTS ANALYSIS FOR "QUALITY," IN IQ-TYPE UNITS

Aircraft	Quality index
F-5E	110
F-16	108
F-18	104
F-15	99
A-6E	96
F-14	82

Variables Used to Measure "Management"

One of the important purposes in using principal components analysis is to reduce the dimensionality of data so that interrelations can be appreciated more readily--perhaps even be shown graphically. To this end, principal components analysis was also applied to indicators intended to describe the way in which aircraft production programs are managed.[2]

1. These IQ-type scores are not perfectly parallel to the actual values commonly found in the IQ-measurement literature. There, the mean is always set to 100, as has been done here, but the value of a standard deviation lies in the range of 14.5 - 16 (depending on the test, etc.). For ease of interpretation (as well as to compress the spread, recognizing the greater uncertainty in the underlying measurements), the value of a standard deviation in the present case has been set at 10, as noted. Both the idea of an IQ-type score for an aircraft and the use of a simpler standard deviation are pure heuristics; they in no way affect the analysis or conclusions.
2. The actual principal components analysis is provided in appendix C.

The indicators used for the analysis, here called "program characteristics," included the following:[1]

- Use of a fly-off competition in choosing a contractor (FYO)
- Buying full cost and schedule control system information (C/SCS)
- Use of incentive features in contracts (ITC)
- Use of multiyear contracting (MYC)
- Significant foreign military sales (FMS)
- High level of competition in subcontracting (CIS)
- Frequent planned model changes (PMC)
- High level of production rates (PRL)
- Stability of production rates (PRS)
- High level of manning in the program office (MPO).

Table 3 shows these characteristics, measured in a binary fashion for simplicity of analysis and presentation. Simple "yes" and "no" answers are in part natural, because the values for the program characteristics are so bimodal that they are virtually dichotomous, and in part judgmental--with the judgment calls ranging from the easily supported to the semiarbitrary. The study team felt that on the whole, the reduction of scaled data to binary form provides a large gain in simplicity of analysis and presentation with only a minor loss of accuracy.[2]

The conversion to binary was done using the following criteria. FYO, MYC, and PRS tend naturally to be binary. Of the other variables,

---

1. In general, program managers have little or no control over the program characteristics listed. Basically, they define the acquisition management environment within which program managers operate. Thus, management as used here does not refer to the effectiveness of program managers and their staffs in carrying out their ongoing work. At the service secretary and CNO/Chief of Staff levels, however, these program characteristics are largely, although not entirely, matters of choice. Hence, they are thought of as observable indicators of management at these higher levels.
2. A further comparison of the differences between the dichotomized data set and the scaled data set, as well as the rationale for the criteria for the dichotomization, are provided in appendix D.

TABLE 3

PROGRAM CHARACTERISTICS

Variables	Observations								
	F-5E	F-14	F-15	F-16	F-18	A-6E	E-2C	P-3C	E-3
Fly-off competition	No	No	No	Yes	No	No	No	No	No
Full C/SCS	Yes	No	Yes	Yes	Yes	No	No	No	Yes
Use of incentive-type contracts	Yes	No	Yes	Yes	Yes	No	No	No	Yes
Multiyear contracting	No	No	No	Yes	No	No	No	No	No
Significant foreign military sales	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes
High level of competition in subcontracting	Yes	No	Yes	Yes	No	No	No	No	Yes
Frequent planned model changes	Yes	No	Yes	Yes	No	No	No	No	Yes
High production rates	Yes	No	Yes	Yes	Yes	No	No	No	No
Stable production rates	No	No	No	Yes	Yes	No	Yes	Yes	Yes
High level of manning in program office	Yes	No	Yes	Yes	No	No	No	No	Yes

C/SCS and ITC were coded as 1 if two or more production contracts had these features. FMS was converted to binary using the number of years the aircraft had been sold to foreign military forces; three or more years was coded as 1. CIS, PRL, and MPO were based on a high/low scale with 33 percent, 50 airplanes per year, and 100 people, respectively, marking the division between high and low. Finally, PMC was converted to binary using the frequency of planned model changes; a model change in six years or less was considered frequent.

A cursory review of table 3 gives the information in table 4. If the program characteristics listed are considered positive indicators of a beneficially "active," high-level management, the table provides a rough idea of which programs have operated in such an environment. This approach, however, does not account for any differences in weighting among the variables. For example, although the F-5E and the E-3 have exactly seven "yes" answers, are high production rates and stability of production equal, or is one more important than the other? Thus, are the F-5E and the E-3 really in the same high-level management environment? To answer these questions, principal components analysis was used.

TABLE 4

COUNT OF THE NUMBER OF "YES" ANSWERS PER AIRCRAFT IN THE BINARY PROGRAM CHARACTERISTICS TABLE

Aircraft	Number of "yes" answers
F-16	10
F-5E	7
E-3	7
F-15	6
F-18	5
E-2C	2
P-3C	2
F-14	0
A-6E	0

Results of Principal Components Analysis for "Management"

Principal components analysis was applied to the ten variables shown in table 3 for nine observations (F-5E, F-14, F-15, F-16, F-18, A-6E, E-2C, P-3C, and E-3). The correlation matrix values ranged from -0.10 to 1.00. These values are not as uniformly high as those found in the principal components analysis for quality. The coefficients used to form the first principal component ranged between 0.04 and 0.39 and

accounted for 56 percent of the variance. Again, the latter two statistics are not as strong as those in the quality analysis. Of the original ten variables, however, FMS and PRS had much lower coefficients than the other variables. Further inspection made it clear that the second principal component accounted for a substantial portion of the total variance, 21 percent, with FMS and PRS contributing heavily. The study team concluded that FMS and PRS were measuring some variable other than management. Upon reflection, this conclusion was not surprising since both FMS and PRS, although part of the overall management environment, are largely controlled by groups outside the services' acquisition processes. In the case of FMS, the contractor, the Defense Security Assistance Agency serving the Secretary of Defense, and the State Department have dominant influences. In the case of stability of production (PRS), Congressional funding levels have a major influence.

Because they appeared to be measuring another concept, FMS and PRS were removed from the list of variables.[1] The principal components analysis was then recalculated using the remaining eight binary indicators and the same nine observations. The new coefficient matrix values ranged between 0.32 and 1.00, and the first principal component coefficients were now more closely balanced (between 0.24 and 0.40) and had an R^2 value of 69 percent (i.e., they now accounted for 69 percent of the total variance).[2]

The statistical significance of this R^2 was checked, using a numerically generated sampling distribution of R^2 values, under the null hypothesis that the underlying binary variables were uncorrelated. The observed R^2 of 69 percent was highly significant--eight standard deviations above the mean of the null hypothesis sampling distribution (see figure 1).

The first principal component scores for each of the nine aircraft, interpreted as "management," are shown in table 5. As these scores have no natural units, they have been restated in IQ-type units for ease of interpretation; that is, they have been rescaled to have a mean equal to 100 and a standard deviation equal to 10.

---

1. Although FYO and MYC were among the lowest coefficients in the first principal component and weighed heavily in the second principal component in the second analysis, they were not removed as FMS and PRS had been as there was no sound reason for doing so. It appeared that their relatively low coefficients were due to their sparse presence (i.e., both FYO and MYC had only one "yes" in the data set). This hypothesis was confirmed in the scaled data results where the coefficients for FYO and MYC were among the highest. (See appendix D).
2. For a closer look at these calculations and results, see appendix C.

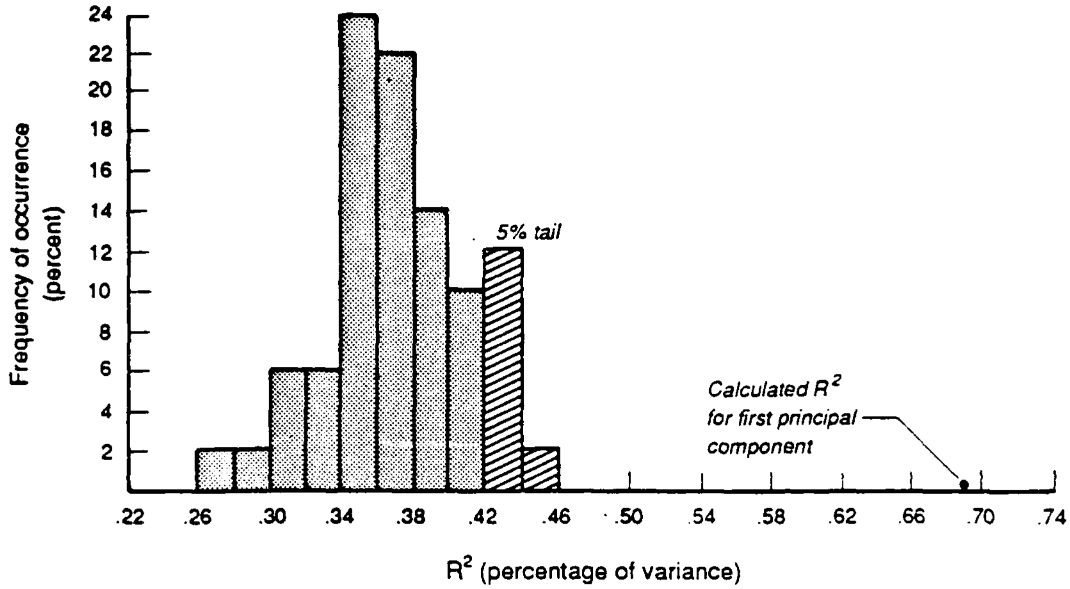

FIG. 1: SAMPLING DISTRIBUTION OF R^2 VALUES COMPARED TO R^2 VALUE CALCULATED FOR FIRST PRINCIPAL COMPONENT

TABLE 5

RESULTS OF THE PRINCIPAL COMPONENTS ANALYSIS FOR "MANAGEMENT," IN IQ-TYPE UNITS

Aircraft	Management index
F-16	115
F-15	109
F-5E	109
E-3	106
F-18	99
A-6E	90
E-2C	90
F-14	90
P-3C	90

Relations Between Sustaining Engineering Usage, Quality, and Management

As described in the preceding sections, the dimensions of sustaining engineering (SE) usage, quality, and management have now each been reduced to single variables; thus, their relations can be more readily analyzed and understood. Because a reliable quality score for the E-2C is not available, and because the missions and mode of operation of the P-3C and E-3 are quite different from those of the other aircraft, these three aircraft have been dropped from the comparisons. The reduction also permits analysis of a more homogeneous group.

In table 6, the IQ-type scores for quality and management for the reduced sample of aircraft are displayed together with the SE usage measure. Although some variation is seen, all of the aircraft show a positive relation between quality and management. No obvious relations appear between management and overall SE usage, or quality and overall SE usage.

TABLE 6

COMPARING "QUALITY" AND "MANAGEMENT" IN IQ-TYPE UNITS AND SE USAGE

Aircraft	Quality index	Management index	SE usage index
F-5E	110	109	0.83
F-16	108	115	1.06
F-18	104	99	1.10
F-15	99	109	1.04
A-6E	96	90	0.82
F-14	82	90	1.04

These relations are more readily interpreted when presented graphically. Figure 2 shows the scores of quality compared with the scores of management. Quality and management appear to have a fairly strong positive correlation (R^2 = 0.58 with a T value of 2.4). In this light, a plausible hypothesis is that high scoring management should be able to economize on SE usage; thus, the two would display a clear, negative relationship. Figure 3, however, shows an essentially random pattern, without any apparent correlation between management and SE usage. Figure 4, displaying the scores of quality compared with overall SE usage, also shows an essentially random pattern.

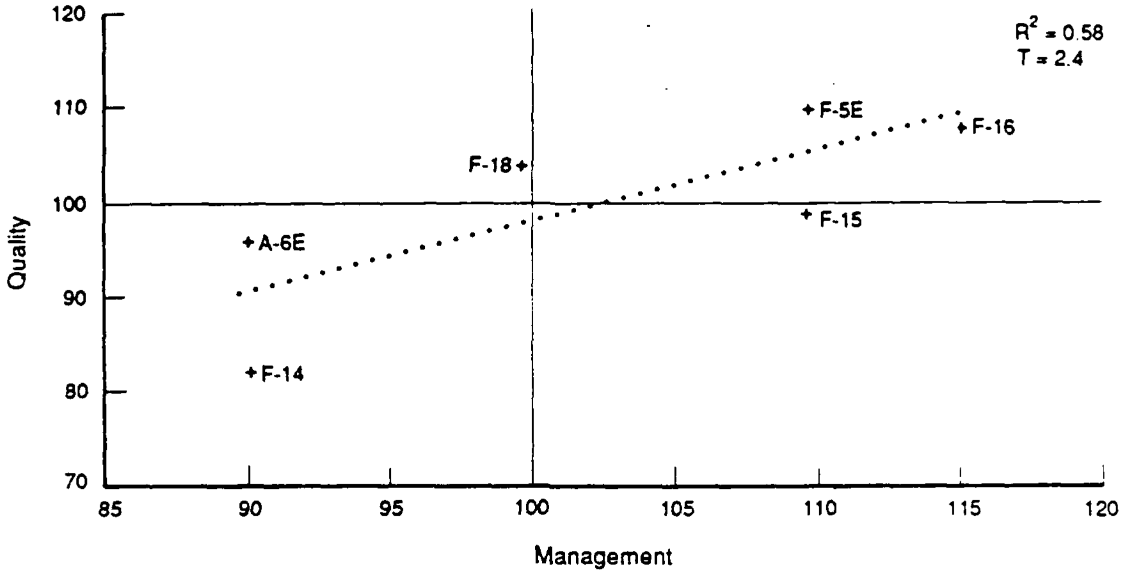

FIG. 2: AIRCRAFT "QUALITY" COMPARED WITH "MANAGEMENT"

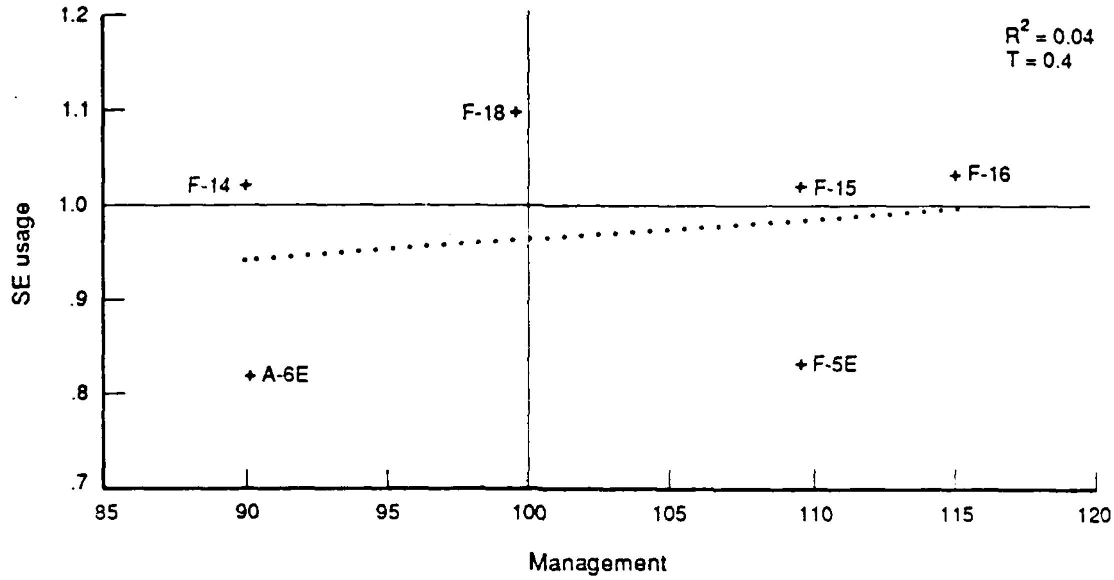

FIG. 3: AIRCRAFT SE USAGE COMPARED WITH "MANAGEMENT"

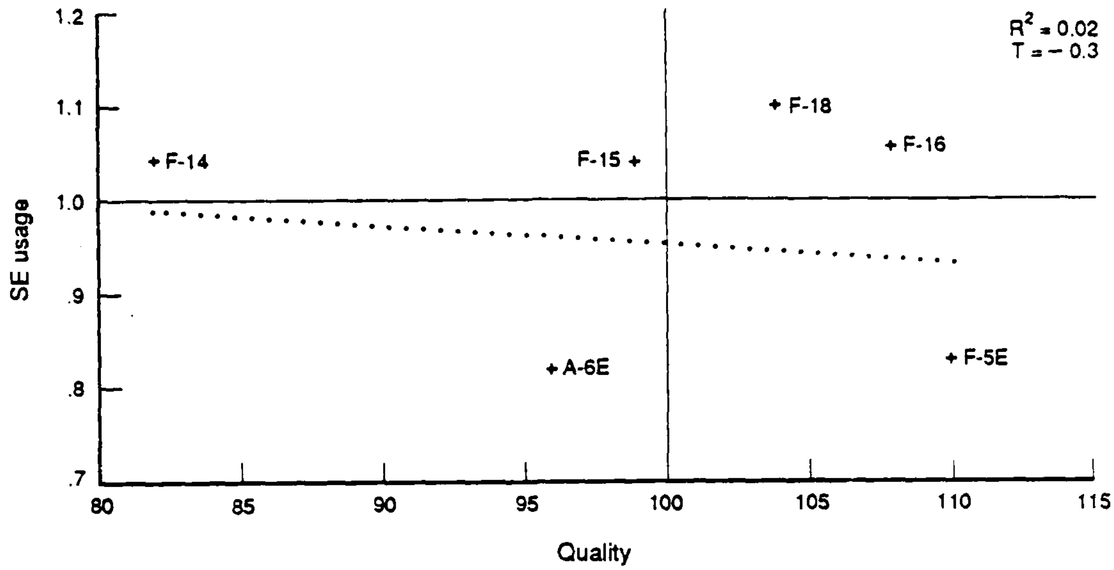

FIG. 4: AIRCRAFT SE USAGE COMPARED WITH "QUALITY"

One possible explanation for the lack of correlation between overall SE usage and quality or management is the lack of an obviously "correct" and intuitively satisfying way of scaling SE usage. Overall SE usage, as presented earlier, is the total actual SE hours over the aircraft's career (or the years for which SE data were available) divided by the total "target" SE hours over the same period, with values greater than 1 representing, on average, greater use of SE than the estimated "target" and values less than 1 representing, on average, lesser use of SE than the estimated "target." These differences are descriptive ratner than normative. For example, if there were a widespread tendency to use "too much" SE, then more SE use than the "target" value would be "bad" and less use would be "good." On the other hand, if average industry practice is "about right," then the measure of interest becomes the amount by which the SE actual/SE target score departs from 1. This departure can be thought of as either the algebraic difference from the norm of 1 or as the absolute difference. Table 7 shows these ways to measure SE usage for the various aircraft in the study's sample. Statistical analysis showed, however, that none of the SE measures in table 7 correlate with either management or quality.

Management, as defined by program characteristics, describes a "management environment" created by choices at the highest levels in the Navy and Air Force. SE usage, however, is determined almost entirely by program offices (and Plant Representative Offices). Because a positive correlation between high-level management and program office management does not necessarily have to exist, the high-level management that

appears to exert pressure on contractors to produce a high quality aircraft does not necessarily influence how much or little SE is used overall.[1]

TABLE 7

POSSIBLE MEASURES OF SE USAGE

Aircraft	Ratio of overall SE actual to SE target (1)	Algebraic difference between column 1 and and ratio of 1.0 (2)	Absolute difference between column 1 and ratio of 1.0 (3)
F-5E	0.83	-0.17	0.17
F-14A	1.04	0.04	0.04
F-15A/B + C/D	1.04	0.04	0.04
F-16A/B + C/D	1.06	0.06	0.06
F-18A/B + C/D	1.10	0.10	0.10
A-6E	0.82	-0.18	0.18
P-3C	1.06	0.06	0.06
E-2C	1.23	0.23	0.23
E-3	1.00	0.00	0.00

The apparent lack of correlation between quality and overall SE usage led the study team to revisit the basic hypothesis that SE investments in particular time periods should result in *changes in quality* in related time periods.

In order to test this hypothesis, measurements of changes in quality and of time-specific SE investments were necessary. Quality measures for operating years two, four, and six were calculated using principal components analysis. The aircraft sample was restricted to those aircraft for which both quality and SE data for the actual first six operating years were available. These six aircraft were the F-14, F-15, F-18, F-5E, P-3C, and E-3. (Unfortunately, SE data for the first four years of the F-16, one of the most interesting aircraft in the study, were not available.)

The variables used to calculate quality for each year were mean flight hours between failures (MFHBF) in that year, mean maintenance

1. Time constraints precluded trying to develop a single measure of management at the program office level. Such an attempt appears feasible and could yield some useful insights on more effective staffing and procedures at that level.

man-hours per flight hour (MMMHFH) in that year, and Class A and B mishap rates at the appropriate flight hours for each aircraft in that year.[1] The change in quality was then simply the difference in the quality scores for each aircraft between years two and four, four and six, and two and six. (Figure 5 shows the change in quality between years two and six.) For this part of the analysis, the quality scores use only the three variables noted above and have not been converted to IQ-type scores. Cumulative SE usage scores for the related time periods were calculated using the method described earlier.

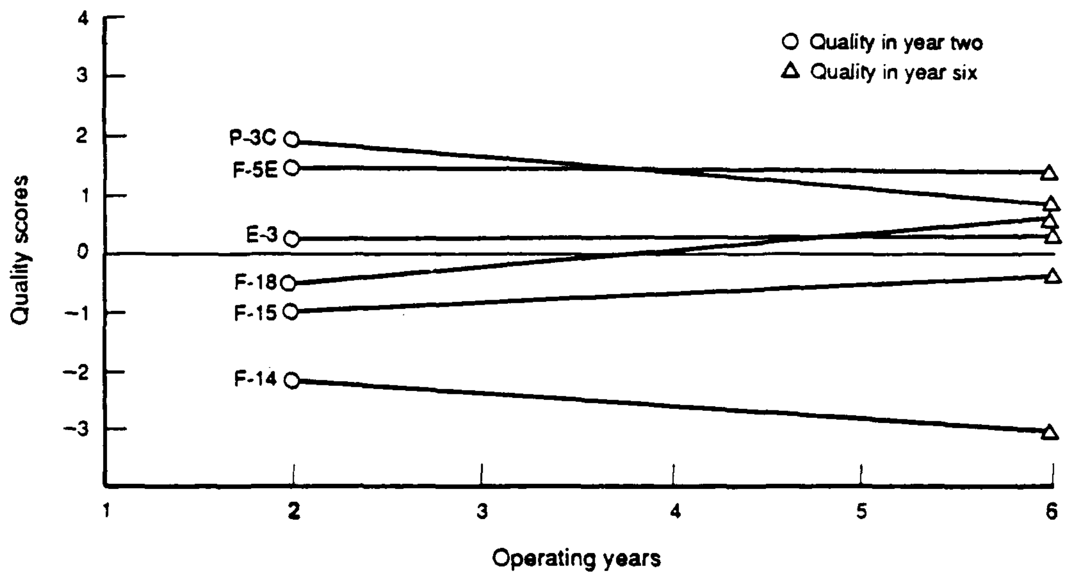

FIG. 5: CHANGE IN QUALITY: YEAR TWO vs. YEAR SIX

Two other factors were also taken into consideration. First, it was necessary to distinguish between completely new aircraft and those representing model changes in an existing aircraft (the F-18 versus the P-3C, for example). The effect of the first year's SE investment was also included on the hypothesis that it represents, in effect, the effort needed to remedy deficiencies in the original design engineering or systems engineering.[2] Thus, the equation takes the form:

$$\Delta Q_{T,t} = B_0 + B_1 \Delta SE_{t,T-1} + B_2 NEW + B_3 SE_1 \quad ,$$

1. For details of this principal components analysis, see appendix E.
2. See page 2 for the definitions of these forms of engineering.

where

$\Delta Q_{T,t}$ = change in quality between t and T

$\Delta SE_{t,T-1}$ = actual SE/target SE for the period t to T-1

NEW = completely new aircraft versus a model change

SE_1 = SE in the first production year.

This regression equation was used to test the hypothesized relations. Because the sample consisted of only six observations, the regression was reestimated for a pooled sample of the six aircraft over two time periods: between year two and year four, and between year four and year six. To test the acceptability of pooling, an *F*-test was used. The null hypothesis that the two data sets came from the same population could not be rejected, so the two data sets were pooled to create a set of twelve observations.[1] Results are shown in table 8.

TABLE 8

A REGRESSION BETWEEN A CHANGE IN QUALITY AND SE INVESTMENTS

Dependent variable: two-year change in quality

N = 12
R^2 = .53
SSE = 1.94

Explanatory variable	Estimated coefficient	*T*-value
Intercept	-3.7	--
Delta SE	4.3	2.4
SE - first year	-1.5	-1.8
NEW	1.5	2.7

The R^2 for the pooled data regressions is not significant at the 5-percent level, but is significant at the 10-percent level. The *Delta SE* investment variable is significant at the 5-percent level, as is the *NEW* aircraft variable.

All in all, these results provide modest support for the hypothesis that SE investments generate a discernible improvement in aircraft

1. See appendix F for a more complete justification for using the pooled data.

quality. This conclusion, obviously, is subject to a number of caveats. For example, only one specification has been considered here in detail, and no investigation has been undertaken of possible correlation among the error terms from period to period. Thus, the results at this stage should be regarded only as suggestive.

The magnitudes of the coefficients may, however, provide a rough idea about the role of SE in maintaining aircraft quality, at least on a relative basis.[1]

The intercept suggests that in the absence of any SE expenditures, "aging" would lead to a decline in quality of 3.7 units over a two-year period. Attaching any value to the intercept is, however, highly conjectural; if nothing else, there are no actual observations in the sample of an aircraft with SE investments anywhere near zero.

One interpretation of the coefficients would be that SE expenditures near the "target" value offset much of the effect of "aging." A typical value for *Delta SE* and *SE - first year* might be 1 (SE actual = SE target). Using this value for both SE variables and inserting 0 for *NEW* yields an estimate of the change in quality score of -0.9 units--or roughly half of a standard deviation.

Thus, the application of typical amounts of SE may offset what otherwise might be the very large effects of "aging." This suggests that deep cuts in SE could be quite risky. On the other hand, the coefficient on *Delta SE* also suggests that making major gains in quality through SE investments could be very difficult. For illustrative purposes, consider an aircraft whose quality is to be improved from one standard deviation below the mean up to the mean; i.e., an increase of 1.6 units of quality. The coefficient on *Delta SE* suggests that this would require a change in the SE usage score, for example, from the target value to 37 percent above it. This is a large movement in SE usage, covering approximately the entire range in the study sample. These findings are consistent, however, with the study team's intuition that the initial design engineering for an aircraft exerts a strong and pervasive effect and that basic design problems cannot be readily overcome with SE.

The above results were for the sample that pooled the two periods, years two through four and years four through six. Although the two

1. As outlined earlier, and as described in more detail in CRM 87-89, the principal component score for each aircraft for each point in time represents a relative measure of quality rather than an absolute measure. To assess changes in absolute terms, it would be preferable to return to the individual indicators of quality, such as MFHBF.

samples were not significantly different by an *F*-test, the coefficients do differ somewhat, but in intuitive ways. Some of the coefficients in the separate regressions and their *T* values are shown in table 9.

TABLE 9

RESULTS OF REGRESSION ANALYSIS OF CHANGES IN QUALITY

	Year two through year four			Year four through year six	
	B	*T*		*B*	*T*
SE_{2-3}	7.5	5.5	SE_{4-5}	7.5	2.3
NEW	3.2	6.8	*NEW*	1.0	1.3
SE_1	-4.4	-5.5	SE_1	-0.3	-0.3

The drop in *T* values and coefficients for *NEW* and SE_1 between the two time periods suggests that *NEW* and SE_1 are less important as the time period moves further away from the first year; it seems fair to speculate that as time progressed they would eventually drop from the regression.

In fact, the first of the two regressions seems generally stronger than the second regression or the pooled data regression: in the first regression, despite the tiny sample size, all the *T* values are significant at the 5-percent level.[1]

Taken together, the three regressions give the impression of a reasonable relation between quality improvement and the flow of SE investments over the appropriate period. This relation is summarized graphically in figure 6. The vertical axis represents the quality improvement between years two and six. The horizontal axis shows the flow of SE investments between years two and five. Both variables are "corrected" for SE in the first year and the NEW variable. Thus, the plot is actually a comparison of residuals, one from a regression with *Delta SE* as the dependent variable, one with the change in quality as the dependent variable. These corrections are important in explaining why the data line up as neatly as they do; the raw data provide a much more random impression.

1. See appendix F for further details.

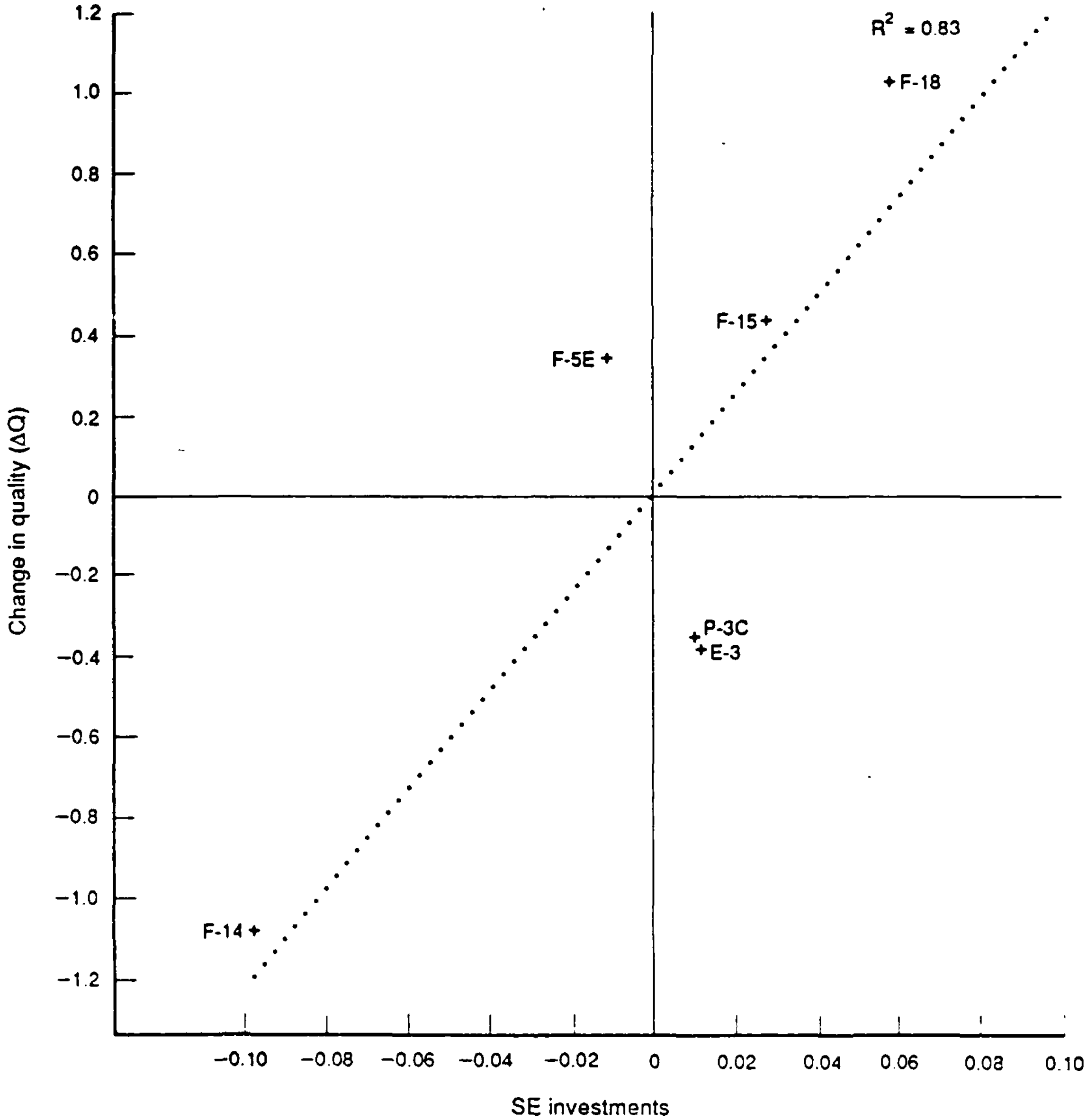

FIG. 6: SE INVESTMENTS FROM YEAR TWO THROUGH YEAR FIVE COMPARED WITH CHANGE IN QUALITY BETWEEN YEAR TWO AND YEAR SIX

CONCLUSIONS

The fact that management and quality are positively correlated supports the hypothesis that a strong, high-level management environment raises the likelihood that a good quality aircraft will result. That management and SE usage do not appear to be correlated is anti-intuitive in that the same management that correlates with quality aircraft could be expected to carefully use SE. The high-level management that succeeds in having contractors produce quality aircraft, however, is not necessarily correlated with the program office management that largely controls SE usage.

Finally, although quality and *overall* SE usage are not directly correlated, a reasonably suggestive positive correlation exists between SE investments in a particular time period and changes in quality related to that time period.

APPENDIX A

COMPONENTS OF SUSTAINING ENGINEERING

APPENDIX A

COMPONENTS OF SUSTAINING ENGINEERING

1. Participating in laying out and modifying production processes.

2. Resolving problems of systems integration.

3. Correcting production problems identified by:
   - Production supervisors and quality assurance personnel
   - Contractor and service flight tests (flight "crabs").

4. Undertaking engineering investigations resulting from fleet-identified problems:
   - Accidents/incidents
   - Unsatisfactory reports by squadron pilots (design-related problems rather than simple malfunctions).

5. Preparing all engineering change proposals (ECPs).

6. Preparing detailed drawings/specs for approved correction of defects (COD) ECPs.

7. Supervising implementation of COD ECP work.

8. Conducting engineering investigations to enhance producibility.

9. Initiating and evaluating value engineering proposals.

10. Conducting engineering efforts to ensure that reliability and maintainability meet contract specification or desired levels.

11. Providing engineering input to configuration control.

12. Updating drawings, rewriting specs, providing engineering input to tech pubs, manuals, etc.

13. Maintaining contractual engineering documentation.

14. Overseeing supplier operations and products.

15. Maintaining liaison with service acquisition managers and their associated field activities.

16. Managing in-house sustaining engineering efforts.

APPENDIX B

ANNOTATED BIBLIOGRAPHY OF RESEARCH MEMORANDUMS
IN THE SERIES ON SUSTAINING ENGINEERING

APPENDIX B

ANNOTATED BIBLIOGRAPHY OF RESEARCH MEMORANDUMS IN THE SERIES ON SUSTAINING ENGINEERING

CNA Research Memorandum 87-40, *Managing Sustaining Engineering in Weapon Systems: Phase 1*, by John E. Keller et al., Mar 1987.

This research memorandum (RM) explains the origin of the VCNO's tasking of CNA to study sustaining engineering. It describes the analytic and procedural approach to the problem as originally conceived and reports some of the earlv substantive findings. The most important of these was that the Navy does not know, nor can it currently find out in a comprehensive and systematic way, the specific services it receives as a result of its annual expenditure of approximately $1 billion on sustaining engineering for aircraft and missiles. (When these preliminary results were briefed to the VCNO, the original tasking was revised and expanded.) The general contents of subsequent documents in this series are also outlined.

CNA Research Memorandum 87-69, *Contractors' Arrangements for Estimating, Controlling, and Recording Sustaining Engineering*, Volume I, by John E. Keller et al., May 1987.

The management of sustaining engineering (SE) is examined in detail for selected weapon systems at six aircraft and missile contractors' plants. The RM discusses various aspects of weapon system engineering and trends in the use of engineering man-hours devoted to SE during full-scale production and subsequent deployment of the systems. Methods of estimating, budgeting, controlling, and accounting for SE hours and costs are discussed.

This volume also summarizes and interprets the formal presentations as well as the less formal discussions with management, engineering, and contracting personnel at the six contractors' plants visited by the CNA study team. In addition, summaries of discussions with personnel from the Air Force F-16 System Program Office (SPO) and Plant Representative Offices (PROs) are included.

CRM 87-69 is supplemented by Volume II (CNA Research Memorandum 87-70, May 1987), which is made up of the CNA questionnaire on SE and the contractors' complete, formal responses.

CNA Research Memorandum 87-70, *Contractors' Arrangements for Estimating, Controlling, and Recording Sustaining Engineering*, Volume II, by John E. Keller et al., May 1987.

This RM (Volume II of CRM 87-69) provides the texts of materials prepared by selected aerospace contractors for a CNA study team

investigating sustaining engineering on Navy (and Air Force) weapon systems. The supplementary material in this research memorandum provides more detailed information than is available in CRM 87-69 (Volume I) and affords the critical reader an opportunity to check the summary findings and interpretations of that volume.

CNA Research Memorandum 87-xxxx, *Estimating Sustaining Engineering "Requirements" for Military Aircraft*, by James M. Jondrow et al., forthcoming.

A statistical analysis of sustaining engineering (SE) for military aircraft is given in this RM. The data used are actual SE hours, over various annual periods between 1970 and 1986, for a pooled sample of nine aircraft: F-5E, F-14, F-15, F-16, F-18, A-6E, P-3C, E-2C, and E-3. Regression-based estimates of SE hours were derived as a function of production lot size, cumulative production quantities, model changes, airframe weight (to represent scale), density of the aircraft (to represent manufacturing complexity), and maximum mach number (to represent design complexity). To allow for contractor lags in adjusting to changes in rates of production, SE hours for the previous year were also included. The interpretation of the estimating equation is as a statistical means of codifying current industry practice, not as a means of determining "requirements."

The estimating equation had an R^2 of 91 percent, and all of the variables had statistically highly significant coefficients--even the model change variable which was plagued by data problems.

Estimated SE hours were compared with actual SE hours for the nine aircraft over the periods for which actual data were available to obtain a measure of relative SE usage. This comparison revealed both one-period differences between actual and target values and extended-period differences, usually toward the end of the production period, during which the actual values appeared to be driven by factors other than the variables in the model.

CNA Research Memorandum 87-xxxx, *Measures of Effectiveness Related to Aircraft Reliability, Maintainability, and Safety and Believed to be Influenced by Sustaining Engineering*, by John E. Keller et al., forthcoming.

Data are provided in both tabular and graphical form for measures of effectiveness related to aircraft reliability, maintainability, and safety and that are believed to be influenced by the application of contractors' sustaining engineering effort. In addition to the data themselves, definitions, commentary, and interpretation are provided.

The measures of effectiveness (MOEs) for which data are provided include: average number of flights required for acceptance; average number of discrepancies per acceptance flight; mean flight hours between

failures (MFHBF); mean maintenance man-hours per flight hour (MMMHFH); mean maintenance man-hours per maintenance action (MMMHMA); ground and in-flight aborts per 100 sorties; and combined Class A and B mishaps per 100,000 flight hours. Data for the MOEs, with some exceptions, are available for the following aircraft: F-5E; F-14A; F-15A/B and C/D; F-16A/B and C/D; F-18A/B; A-6E; P-3C; E-2C; and E-3A/B/C. The data generally cover the period from the type-model-series's first full operational year through 1985 or 1986. F-14A and F-18A/B data are also available, by block. Navy and Air Force data have been made very nearly fully consistent. With the exception of acceptance testing histories, the data relate only to those parts of the aircraft (work unit or system codes) for which the prime contractor and his sustaining engineering are responsible.

CNA Research Memorandum 87-89, *Measures of Aircraft Reliability, Maintainability, and Safety: Do They Measure "System Quality"?* by Peter E. Hilsenrath et al., Jun 1987.

This research memorandum applies principal components analysis to nine indicators of aircraft reliability, maintainability, and safety. The indicators are standard readiness measures, such as mean time between failure at different points in the aircraft's career. The data are adjusted to include only the airframe, the portion of the aircraft the prime contractor is responsible for. The assumption behind the analysis is that the observable variables are indicators of an underlying unobservable variable, "airframe quality." This principal components analysis provides a quality "score" for each aircraft. Five of the six aircraft analyzed fall within one standard deviation of the average score; only one falls below. The scores for the first principal component account for 85 percent of the variation in the original indicators, which is highly significant in a statistical sense. This finding supports the initial hypothesis, that there is such a thing as "quality," which is a major source of the variation across aircraft in the nine indicators.

CNA Research Memorandum 87-92, *Relations Between Sustaining Engineering, Methods of Management, and System Quality*, by Barbara L. Tuxbury et al., Dec 1987.

One of the major elements in the Vice Chief of Naval Operations (VCNO) tasking for the sustaining engineering (SE) study was to examine the relations, if any, between SE usage, methods of management, and measures of effectiveness related to reliability, maintainability, and safety. Another research memorandum (RM) in this series estimates relative SE usage among a large sample of Navy and Air Force aircraft. Still another RM in this series examines measures of effectiveness for aircraft reliability, maintainability, and safety. That RM described how it was found possible, using principal components analysis, to combine multiple measures of effectiveness into a single measure of aircraft "quality."

In order to complete the comparisons requested in the tasking, a measure of management is necessary. The same technique of principal components analysis has been employed to combine multiple program characteristics into a single measure of "management." (These program characteristics describe the type of "management environment," created by choices at the service secretary and CNO/Chief of Staff levels, within which a program office works. Hence, this kind of "management" is not an indicator of the program office's effectiveness.) The analysis found that the first principal component accounted for a statistically significant percentage of the variation in the program characteristics, thus supporting the idea of a single underlying variable, "management."

The three single measures--relative SE usage, "quality," and "management"--were then used to seek out relations, if any. The analysis revealed that quality and management show a significant positive correlation. Management (as defined by program characteristics) and overall relative SE usage show no obvious correlation. Although quality and overall relative SE usage show no apparent correlation, SE investments in a particular time period and changes in quality related to that time period do show a positive correlation.

CNA Research Memorandum 87-xxxx, *The Impact of Sustaining Engineering and of Aging on Aircraft Reliability, Maintainability, and Safety*, by Barbara L. Tuxbury et al., forthcoming.

The ways in which military aircraft (actually airframes) "age," or change in "quality" with time or use are explored in this RM. Quality includes measures of reliability, maintainability, and safety. Because sustaining engineering (SE) is used to support both the production process and operational aircraft, there should be evidence of a favorable impact on the quality of aircraft newly off the production line and on quality measures, over time, for operational aircraft. In fact, reliability and maintainability for aircraft newly off the production line are clearly improved, and the improvement may be attributable, in part, to SE. Safety measures for operational aircraft are also improved, and this improvement persists over time. There is, however, a tendency for the measures of reliability and maintainability to worsen over time--sometimes dramatically; and there is some evidence of a tendency among certain aircraft for successive and initially better blocks to converge to a common level of quality. Such tendencies must be taken into account in trying to assess the effect of SE on aging. A related finding of the research is that patterns of aging are obscured when aircraft are analyzed as a fleet; the continued introduction of new, better aircraft masks the decline in quality of the preexisting inventory.

During the course of studying the aging problem, related issues were investigated in a preliminary fashion. The issues included: the use of work unit/system codes to identify key contributors to low reliability and maintainability (thus providing the basis for more effectively directing future SE efforts), aircraft procurement requirements

to ensure having a specific number of aircraft that could even become mission capable, and the long-term cost-effectiveness of buying new aircraft versus remanufacturing old aircraft.

The final portion of the RM outlines a number of additional issues that appear worthy of continued or fresh analysis.

CNA Research Memorandum 87-xxxx, *Sustaining Engineering Hours and Costs, Manufacturing Hours and Costs, Other Hours and Costs, and Related Aircraft Production*, by John E. Keller et al., forthcoming.

Data are provided in both tabular and graphical form on sustaining engineering hours and costs, manufacturing hours and costs, and other contractor hours and costs related to annual aircraft production buys. In addition to the data themselves, definitions, commentary, and interpretation are provided.

The data are from two main sources: the Contractor Cost Data Report (Forms 1921-1 as required by DOD Instruction 7000.11) and a special CNA-designed data format. Data from these two sources could not be made congruent and, hence, special emphasis was placed on ensuring maximum accuracy and consistency among contractors using the CNA-designed format. Data were generated for the F-5E, F-14, F-15, F-16, F-18, AV-8B, A-6E, P-3C, E-2C, and E-3. In most cases, the data covered the full production history of the aircraft through 1986.

These original data showed widely different levels of sustaining engineering (SE) hour use, both in total and on a per aircraft basis. The SE hour disparities created a need to recognize differences in aircraft size, complexity, etc. The subsequent analytic effort to deal with these differences is reported in the related RM, *Estimating Sustaining Engineering "Requirements" in Military Aircraft*, which is forthcoming.

APPENDIX C

PRINCIPAL COMPONENTS ANALYSES

TABLE C-1

PRINCIPAL COMPONENTS ANALYSIS

(Nine observations and ten variables--binary data)

Simple statistics

	FYO	CSS	ITC	MYC	FMS	CIS	PMC	PRL	PRS	MPO
Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Standard deviation	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Correlations

	FYO	CSS	ITC	MYC	FMS	CIS	PMC	PRL	PRS	MPO
FYO	1.00	0.32	0.32	1.00	0.25	0.40	0.40	0.40	0.32	0.40
CSS	0.32	1.00	1.00	0.32	0.32	0.80	0.80	0.80	0.10	0.80
ITC	0.32	1.00	1.00	0.32	0.32	0.80	0.80	0.80	0.10	0.80
MYC	1.00	0.32	0.32	1.00	0.25	0.40	0.40	0.40	0.32	0.40
FMS	0.25	0.32	0.32	0.25	1.00	0.16	0.16	0.16	0.79	0.16
CIS	0.40	0.80	0.80	0.40	0.16	1.00	1.00	0.55	-0.10	1.00
PMC	0.40	0.80	0.80	0.40	0.16	1.00	1.00	0.55	-0.10	1.00
PRL	0.40	0.80	0.80	0.40	0.16	0.55	0.55	1.00	-0.10	0.55
PRS	0.32	0.10	0.10	0.32	0.79	-0.10	-0.10	-0.10	1.00	-0.10
MPO	0.40	0.80	0.80	0.40	0.16	1.00	1.00	0.55	-0.10	1.00

	Eigenvalue	Difference	Proportion	Cumulative
First principal component	5.59	3.49	0.56	0.56
Second principal component	2.10	0.80	0.21	0.77
Third principal component	1.30	0.55	0.13	0.90
Fourth principal component	0.75	0.54	0.07	0.97
Fifth principal component	0.21	0.16	0.02	0.99
Sixth principal component	0.05	0.05	0.01	1.00
Seventh principal component	0.00	0.00	0.00	1.00
Eighth principal component	0.00	0.00	0.00	1.00
Ninth principal component	0.00	0.00	0.00	1.00
Tenth principal component	0.00	0.00	0.00	1.00

TABLE C-1 (Continued)

Coefficients

	First principal component	Second principal component	Third principal component	Fourth principal component	Fifth principal component	Sixth principal component	Seventh principal component	Eighth principal component	Ninth principal component	Tenth principal component
FYO	0.25	0.38	-0.52	-0.04	-0.01	-0.14	-0.19	0.10	0.00	-0.67
CSS	0.39	-0.08	0.24	-0.23	-0.33	-0.35	0.00	0.00	0.71	0.00
ITC	0.39	-0.08	0.24	-0.23	-0.33	-0.35	0.00	0.00	-0.71	0.00
MYC	0.25	0.38	-0.52	-0.04	-0.01	-0.14	0.19	-0.10	0.00	0.67
FMS	0.14	0.49	0.48	0.10	0.65	-0.30	0.00	0.00	0.00	0.00
CIS	0.39	-0.17	-0.01	0.35	0.07	0.16	0.10	0.80	0.00	0.10
PMC	0.39	-0.17	-0.01	0.35	0.07	0.16	0.62	-0.46	0.00	-0.25
PRL	0.32	-0.08	0.00	-0.71	0.34	0.53	0.00	0.00	0.00	0.00
PRS	0.04	0.61	0.33	0.11	-0.49	0.52	0.00	0.00	0.00	0.00
MPO	0.39	-0.17	-0.01	0.35	0.07	0.16	-0.73	-0.34	0.00	0.15

Aircraft	First principal component	Second principal component
A-6E	-2.47	-0.89
F-14	-2.47	-0.89
E-2C	-2.11	1.23
P-3C	-2.11	1.23
F-18	-0.03	0.80
E-3	1.58	-0.01
F-15	1.83	-2.28
F-5E	2.11	-1.31
F-16	3.66	2.13

TABLE C-2

PRINCIPAL COMPONENTS ANALYSIS
(Nine observations and eight variables--binary data)

Simple statistics

	FYO	CSS	ITC	MYC	CIS	PMC	PRL	MPO
Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Standard deviation	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Correlations

	FYO	CSS	ITC	MYC	CIS	PMC	PRL	MPO
FYO	1.00	0.32	0.32	1.00	0.40	0.40	0.40	0.40
CSS	0.32	1.00	1.00	0.32	0.80	0.80	0.80	0.80
ITC	0.32	1.00	1.00	0.32	0.80	0.80	0.80	0.80
MYC	1.00	0.32	0.32	1.00	0.40	0.40	0.40	0.40
CIS	0.40	0.80	0.80	0.40	1.00	1.00	0.55	1.00
PMC	0.40	0.80	0.80	0.40	1.00	1.00	0.55	1.00
PRL	0.40	0.80	0.80	0.40	0.55	0.55	1.00	0.55
MPO	0.40	0.80	0.80	0.40	1.00	1.00	0.55	1.00

	Eigenvalue	Difference	Proportion	Cumulative
First principal component	5.50	3.94	0.69	0.69
Second principal component	1.56	0.79	0.19	0.88
Third principal component	0.77	0.60	0.10	0.98
Fourth principal component	0.17	0.17	0.02	1.00
Fifth principal component	0.00	0.00	0.00	1.00
Sixth principal component	0.00	0.00	0.00	1.00
Seventh principal component	0.00	0.00	0.00	1.00
Eighth principal component	0.00	0.00	0.00	1.00

TABLE C-2 (Continued)

	Coefficients							
	First principal component	Second principal component	Third principal component	Fourth principal component	Fifth principal component	Sixth principal component	Seventh principal component	Eighth principal component
FYO	0.24	0.66	-0.01	-0.09	0.30	0.38	-0.52	0.00
CSS	0.39	-0.20	0.28	-0.48	0.00	0.00	0.00	0.71
ITC	0.39	-0.20	0.28	-0.48	0.00	0.00	0.00	-0.71
MYC	0.24	0.66	-0.01	-0.09	-0.30	-0.38	0.52	0.00
CIS	0.40	-0.13	-0.36	0.16	0.73	-0.29	0.22	0.00
PMC	0.40	-0.13	-0.36	0.16	-0.28	0.69	0.34	0.00
PRL	0.33	-C.02	0.66	0.67	0.00	0.00	0.00	0.00
MPO	0.40	-0.13	-0.36	0.16	-0.45	-0.40	-0.55	0.00

Aircraft	First principal component	Second principal component
F-14	-2.26	0.33
A-6E	-2.26	0.33
E-2C	-2.26	0.33
P-3C	-2.26	0.33
F-18	-0.16	-0.48
E-3	1.48	-1.16
F-5E	2.10	-1.21
F-15	2.10	-1.21
F-16	3.55	2.74

APPENDIX D

COMPARISON OF PRINCIPAL COMPONENTS ANALYSES USING BINARY AND SCALED DATA

APPENDIX D

COMPARISON OF PRINCIPAL COMPONENTS ANALYSES USING BINARY AND SCALED DATA

In order to determine if dichotomizing the values for program characteristics distorted the results of the principal components analysis, a comparison was made using both scaled and dichotomized variables. In the original dichotomization, the scaled data were studied and judgments were made about reasonable bases for classifying the data into simple "yes" and "no" answers. (See table 3 in the main text.) In the case of both fly-off competition and multiyear procurements this was simple: there was only one example of each. The one example of fly-off competition was between the YF-16 and the YF-17. Because high-level "management" choices are being evaluated, only the F-16 is given credit for a fly-off competition, as the Air Force instigated the competition that led to its choice. A heavily reworked form of the YF-17 later became the F-18, but the F-18 was substantially different from the YF-17 and was not developed primarily as a result of the original competition. Thus, fly-off competition was scored "no" for the F-18. In either case, however, this characteristic is naturally dichotomous. Similarly, there is only one example of multiyear procurements (the F-16), and it has had two four-year procurements of that kind. This experience is neither short term nor freakish. Again, the variable is naturally dichotomous.

Program office staffing is a characteristic so highly bimodal that it was best represented by a simple high-low score. A group of program offices has staff sizes between 20 and 50. No other values are seen until another group emerges with staff sizes between roughly 130 and 500. There is no question that there are just two groups: large and small. (If pressed, of course, the large group could be divided into medium and large, but the advantage to that is not obvious. Moreover, additional data would be needed to make the division between medium and large.) Although bigger is not necessarily better organizationally, the weighting of this characteristic in the principal components analysis was quite heavy. Furthermore, the importance of size pertains to staffing of *the program office only*--not the organizational superstructure above it. The finding is supported, too, by observation of many of the small-size program offices; they appear to be stretched very thin and are forced into playing catch-up with the contractor.

Incidentally, this program characteristic illustrates many of the "counting" problems that arise from trying to use scaled variables. Should staff size be measured at its minimum, its maximum, or by a time-weighted average? Should size be related to contract value? To production rates? Should it be lagged or not? Should rank or grade of the staff be taken into account? Would average program office cost be better? Averaged over what period of time? If program staffing and procedures were a key issue (and they might well be worth a separate study),

then all of the questions noted above would be worth answering. However, for the present study, a simple distinction between large and small seemed adequate and appropriate.

Program characteristics, such as high and low production rates and frequency of planned model changes, admittedly are much more judgmental. Nevertheless, there was some basis for the judgments. For example, conventional wisdom holds that four aircraft per month is a minimum efficient production rate; hence, annual buy sizes above or below 50 were chosen as being high or low production rates. The six-year test on planned model changes does, indeed, verge on the arbitrary. With the exception of the F-18, however, all of the aircraft fell fairly clearly on one side of that dividing line or the other. For example, the F-14, A-6E, E-2C, and P-3C all have been unchanged for a decade or more. The F-18 A/B became a C/D in FY 1986, thus just missing the six-year dividing line. When the VCNO was briefed in April 1986, however, the FY 1986 buy was advertised as a major block upgrade, not as a model change, thus weakening its claim as a *planned* model change. (Accepting major block upgrades as equivalent to model changes opens a dismaying Pandora's box.)

The buying of full C/SCS, the use of incentive type contracts, the use of competition in subcontracting, the amount of stability in production, and the significance of foreign military sales can all be scaled, but once again the scaling shows trends toward two groups of data. Table D-1 shows the R^2 and T values for regressions comparing the scaled values of the data (as shown in table D-2) to the binary measures for the data (as shown in table 3 in the main text). Except for foreign military sales and competition in subcontracting, the binary measures appear to correspond well to the scaled measures.

In order to see how these differences might affect the results of the original analysis with binary data, principal components were calculated using scaled values for the variables. The results of these analyses are shown in figure D-1; they are also shown graphically in figure D-2.[1] The scaled variables provide a slightly greater spread in the distribution of scores, but overall they present a picture similar to that for the binary data.

1. The actual principal component analyses are shown in tables D-3 and D-4.

TABLE D-1

CORRELATION BETWEEN BINARY AND SCALED MEASURES
(R^2 = percent)

FYO	R^2 = 100	T = *
CSS	R^2 = 72	T = 4.2
ITC	R^2 = 72	T = 4.2
MYC	R^2 = 100	T = *
FMS	R^2 = 33	T = 1.8
CIS	R^2 = 53	T = 2.8
PMC	R^2 = 60	T = -3.2
PRL	R^2 = 85	T = 6.3
PRS	R^2 = 75	T = 4.6
MPO	R^2 = 62	T = 3.4

* The T value is undefined when R^2 = 100 percent.

TABLE D-2

PROGRAM CHARACTERISTICS WITH SCALED VALUES

	Observations								
Variables	F-5E	F-14	F-15	F-16	F-18	A-6E	E-2C	P-3C	E-3
Fly-off competition	No	No	No	Yes	No	No	No	No	No
Full C/SCS[a]	33.0	0.0	57.0	78.0	38.0	0.0	6.0	12.0	92.0
Use of incentive-type contracts[b]	33.0	0.0	50.0	78.0	38.0	0.0	6.0	12.0	92.0
Multiyear contracting[c]	0.0	0.0	0.0	67.0	0.0	0.0	0.0	0.0	0.0
Foreign military sales[d]	91.0	13.0	13.0	31.0	34.0	0.0	17.0	23.0	35.0
Competition in subcontracting[e]	35.0	20.0	30.0	50.0	30.0	18.0	20.0	25.0	30.0
Planned model changes[f]	5.0	15.0	5.0	2.7	3.5	17.0	16.0	17.0	4.0
Production rates[g]	119.1	41.6	71.8	141.3	105.3	10.8	8.1	14.1	7.3
Stable production rates[h]	19.0	28.0	20.0	74.0	54.0	29.0	55.0	38.0	63.0
Level of manning in program office[i]	138.0	30.0	150.0	480.0	40.0	30.0	20.0	20.0	288.0

a. Percentage of total years full C/SCS bought.
b. Percentage of total years incentive-type contracts used.
c. Percentage of total years contract covered by a multiyear contract.
d. Percentage of total production sold to foreign military forces.
e. Percentage of subcontracting awarded competitively.
f. Total number of years in production divided by total number of models.
g. Total aircraft produced divided by total years in production.
h. Lowest annual number of aircraft contracted for, divided by highest number, multiplied by 100.
i. Number of staff in 1986, except for the F-5E, which is out of production (peak strength used).

<table>
<tr><th colspan="4">BINARY DATA</th><th colspan="4">SCALED DATA</th></tr>
<tr><td colspan="4">9 observations and 10 variables</td><td colspan="4">9 observations and 10 variables</td></tr>
<tr><td rowspan="2">$R^2 = 56$</td><td colspan="2">IQ Scores</td><td rowspan="2">First principal component coefficients range from .04 to .39. Low coefficients for FMS and PRS. Second principal component coefficients are heavy for FMS and PRS.</td><td rowspan="2">$R^2 = 63$</td><td colspan="2">IQ Scores</td><td rowspan="2">First principal component coefficients range from .15 to .39. Low coefficients for FMS and PRS. Second principal component coefficients are heavy for FMS and PRS.</td></tr>
<tr><td>F-16
F-5E
F-15
E-3
F-18
P-3C
E-2C
F-14
A-6E</td><td>116
109
108
107
100
91
91
90
90</td><td>F-16
E-3
F-5E
F-18
F-15
P-3C
E-2C
F-14
A-6E</td><td>121
106
103
102
101
93
92
92
90</td></tr>
<tr><td colspan="4">9 observations and 8 variables</td><td colspan="4">9 observations and 8 variables</td></tr>
<tr><td rowspan="2">$R^2 = 69$</td><td colspan="2">IQ Scores</td><td rowspan="2">First principal component coefficients range from .24 to .40.</td><td rowspan="2">$R^2 = 73$</td><td colspan="2">IQ Scores</td><td rowspan="2">First principal component coefficients range from .30 to .40.</td></tr>
<tr><td>F-16
F-5E
F-15
E-3
F-18
P-3C
F-14
E-2C
A-6E</td><td>115
109
109
106
99
90
90
90
90</td><td>F-16
E-3
F-5E
F-15
F-18
P-3C
F-14
E-2C
A-6E</td><td>122
106
103
103
101
93
92
91
90</td></tr>
</table>

FIG. D-1: PRINCIPAL COMPONENT ANALYSES OF PROGRAM CHARACTERISTICS

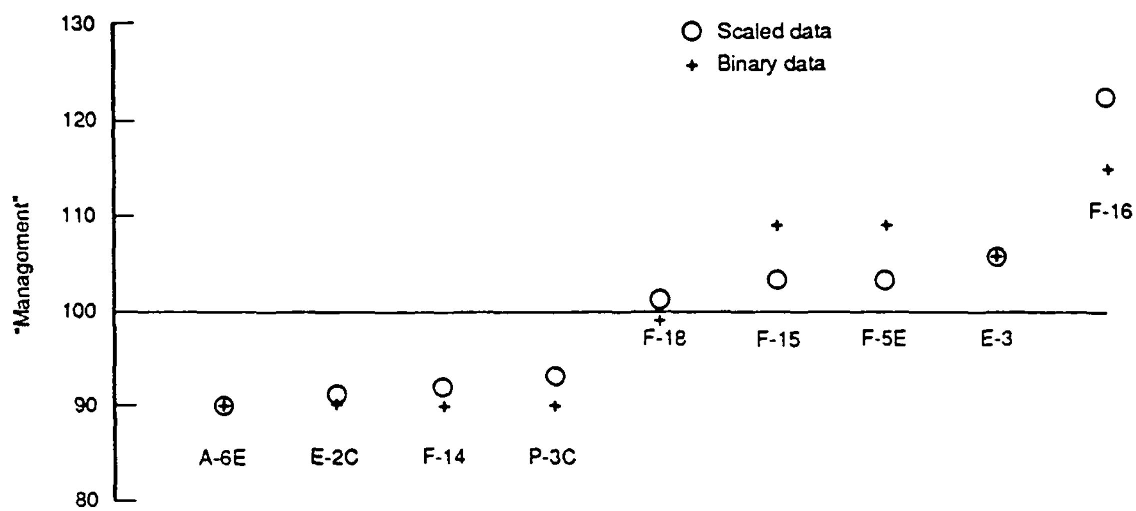

FIG. D-2: SCORES BASED ON SCALED DATA AND ON BINARY DATA

TABLE D-3

PRINCIPAL COMPONENTS ANALYSIS
(Nine observations and ten variables--scaled data)

Simple statistics

	FYO	CSS	ITC	MYC	FMS	CIS	PMC	PRL	PRS	MPO
Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Standard deviation	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Correlations

	FYO	CSS	ITC	MYC	FMS	CIS	PMC	PRL	PRS	MPO
FYO	1.00	0.47	0.47	1.00	0.04	0.81	-0.39	0.59	0.60	0.82
CSS	0.47	1.00	1.00	0.47	0.28	0.75	-0.86	0.39	0.52	0.85
ITC	0.47	1.00	1.00	0.47	0.28	0.75	-0.86	0.39	0.52	0.85
MYC	1.00	0.47	0.47	1.00	0.04	0.81	-0.39	0.59	0.60	0.82
FMS	0.04	0.28	0.28	0.04	1.00	0.49	-0.53	0.56	-0.09	0.24
CIS	0.81	0.75	0.75	0.81	0.49	1.00	-0.79	0.82	0.45	0.88
PMC	-0.39	-0.86	-0.86	-0.39	-0.53	-0.79	1.00	-0.73	-0.31	-0.69
PRL	0.59	0.39	0.39	0.59	0.56	0.82	-0.73	1.00	0.10	0.51
PRS	0.60	0.52	0.52	0.60	-0.09	0.45	-0.31	0.10	1.00	0.58
MPO	0.82	0.85	0.85	0.82	0.24	0.88	-0.69	0.51	0.58	1.00

	Eigenvalue	Difference	Proportion	Cumulative
First principal component	6.30	4.62	0.63	0.63
Second principal component	1.68	0.46	0.17	0.80
Third principal component	1.22	0.76	0.12	0.92
Fourth principal component	0.46	0.16	0.05	0.97
Fifth principal component	0.30	0.27	0.03	1.00
Sixth principal component	0.03	0.03	0.00	1.00
Seventh principal component	0.00	0.00	0.00	1.00
Eighth principal component	0.00	0.00	0.00	1.00
Ninth principal component	0.00	0.00	0.00	1.00
Tenth principal component	0.00	0.00	0.00	1.00

TABLE D-3 (Continued)

Coefficients

	First principal component	Second principal component	Third principal component	Fourth principal component	Fifth principal component	Sixth principal component	Seventh principal component	Eighth principal component	Ninth principal component	Tenth principal component
FYO	0.32	0.35	0.33	-0.05	0.12	-0.04	-0.20	0.33	0.71	0.00
CSS	0.34	-0.09	-0.44	-0.14	0.08	0.17	0.19	0.30	0.00	0.71
ITC	0.34	-0.09	-0.44	-0.14	0.08	0.17	0.19	0.30	0.00	-0.71
MYC	0.32	0.35	0.33	-0.05	0.12	-0.04	-0.20	0.33	-0.71	0.00
FMS	0.15	-0.59	0.19	0.62	0.39	-0.09	-0.05	0.20	0.00	0.00
CIS	0.38	-0.07	0.18	-0.01	0.07	0.71	-0.17	-0.52	0.00	0.00
PMC	-0.33	0.34	0.17	0.15	0.44	0.35	0.63	0.09	0.00	0.00
PRL	0.28	-0.27	0.48	-0.15	-0.49	-0.08	0.58	0.04	0.00	0.00
PRS	0.24	0.41	-0.24	0.72	-0.41	-0.03	0.12	-0.12	0.00	0.00
MPO	0.38	0.12	-0.08	-0.12	0.44	-0.54	0.25	-0.53	0.00	0.00

Aircraft	First principal component	Second principal component
A-6E	-2.53	0.96
F-14	-2.13	0.37
E-2C	-1.92	1.02
P-3C	-1.79	0.49
F-15	0.26	-0.77
F-18	0.40	-0.77
F-5E	0.65	-2.71
E-3	1.63	-0.18
F-16	5.41	1.59

TABLE D-4

PRINCIPAL COMPONENTS ANALYSIS
(Nine observations and eight variables--scaled data)

Simple statistics

	FYO	CSS	ITC	MYC	CIS	PMC	PRL	MPO
Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Standard deviation	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Correlations

	FYO	CSS	ITC	MYC	CIS	PMC	PRL	MPO
FYO	1.00	0.47	0.47	1.00	0.81	-0.39	0.59	0.82
CSS	0.47	1.00	1.00	0.47	0.75	-0.86	0.39	0.85
ITC	0.47	1.00	1.00	0.47	0.75	-0.86	0.39	0.85
MYC	1.00	0.47	0.47	1.00	0.81	-0.39	0.59	0.82
CIS	0.81	0.75	0.75	0.81	1.00	-0.79	0.82	0.88
PMC	-0.39	-0.86	-0.86	-0.39	-0.79	1.00	-0.73	-0.69
PRL	0.59	0.39	0.39	0.59	0.82	-0.73	1.00	0.51
MPO	0.82	0.85	0.85	0.82	0.88	-0.69	0.51	1.00

	Eigenvalue	Difference	Proportion	Cumulative
First principal component	5.84	4.53	0.73	0.73
Second principal component	1.31	0.54	0.16	0.89
Third principal component	0.77	0.72	0.10	0.99
Fourth principal component	0.05	0.02	0.01	1.00
Fifth principal component	0.03	0.03	0.00	1.00
Sixth principal component	0.00	0.00	0.00	1.00
Seventh principal component	0.00	0.00	0.00	1.00
Eighth principal component	0.00	0.00	0.00	1.00

TABLE D-4 (Continued)

Coefficients

	First principal component	Second principal component	Third principal component	Fourth principal component	Fifth principal component	Sixth principal component	Seventh principal component	Eighth principal component
FYO	0.34	0.48	0.20	-0.27	0.19	-0.03	0.71	0.00
CSS	0.35	-0.42	0.22	-0.03	0.21	0.33	0.00	0.71
ITC	0.35	-0.42	0.22	-0.03	0.21	0.32	0.00	-0.71
MYC	0.34	0.48	0.20	-0.27	0.19	-0.03	-0.71	0.00
CIS	0.40	0.10	-0.17	0.78	0.29	-0.32	0.00	0.00
PMC	-0.34	0.38	0.37	0.46	0.03	0.63	0.00	0.00
PRL	0.30	0.19	-0.74	-0.05	-0.18	0.53	0.00	0.00
MPO	0.39	0.02	0.32	0.16	-0.85	-0.05	0.00	0.00

Aircraft	First principal component	Second principal component
A-6E	-2.30	0.69
E-2C	-2.08	0.49
F-14	-1.94	0.70
P-3C	-1.77	0.47
F-18	0.25	-0.57
F-15	0.59	-0.25
F-5E	0.64	-1.05
E-3	1.40	-2.17
F-16	5.24	1.68

APPENDIX E

PRINCIPAL COMPONENTS ANALYSES FOR QUALITY IN DIFFERENT TIME PERIODS

APPENDIX E

PRINCIPAL COMPONENTS ANALYSES FOR QUALITY IN DIFFERENT TIME PERIODS

In order to test the hypothesis that SE investments in particular time periods should result in changes in quality in related periods, measurements of changes in quality were necessary. Quality measures for operating years two, four, and six were calculated using principal components analysis. The aircraft sample was restricted to those aircraft for which both quality and SE data were available in operating years two, four, and six. The variables used to calculate quality for each year were MFHBF in that year, MMMHFH in that year, and Class A and B mishap rates at the appropriate flight hours for each aircraft in that year. Tables E-1 through E-3 show the actual principal components analyses and resulting quality scores.

TABLE E-1

PRINCIPAL COMPONENTS ANALYSIS
(six observations and three variables--quality for year two)

Simple statistics

	MFHBF2	MMHFH2	ANBMR2
Mean	2.10	6.17	7.63
Standard deviation	0.98	4.01	6.29

Correlations

	MFHBF2	MMHFH2	ANBMR2
MFHBF2	1.00	-0.81	-0.41
MMHFH2	-0.81	1.00	0.80
ANBMR2	-0.41	0.80	1.00

	Eigenvalue	Difference	Proportion	Cumulative
First principal component	2.36	1.76	0.79	0.79
Second principal component	0.60	0.55	0.20	0.99
Third principal component	0.05		0.01	1.00

Coefficients

	First principal component	Second principal component	Third principal component
MFHBF2	-0.54	0.70	0.46
MMHFH2	0.64	-0.01	0.77
ANBMR2	0.54	0.71	-0.45

Aircraft	First principal component
P-3C	-1.91
F-5E	-1.49
E-3	-0.25
F-18	0.50
F-15	1.00
F-14	2.15

TABLE E-2

PRINCIPAL COMPONENTS ANALYSIS
(six observations and three variables--quality for year four)

	Simple statistics		
	MFHBF4	MMHFH4	ANBMR4
Mean	2.72	5.97	5.45
Standard deviation	1.14	4.92	4.61

	Correlations		
	MFHBF4	MMHFH4	ANBMR4
MFHBF4	1.00	-0.84	-0.50
MMHFH4	-0.84	1.00	0.85
ANBMR4	-0.50	0.85	1.00

	Eigenvalue	Difference	Proportion	Cumulative
First principal component	2.47	1.97	0.82	0.82
Second principal component	0.50	0.47	0.17	0.99
Third principal component	0.03		0.01	1.00

	Coefficients		
	First principal component	Second principal component	Third principal component
MFHBF4	-0.55	0.72	0.43
MMHFH4	0.63	0.01	0.78
ANBMR4	0.55	0.70	-0.46

Aircraft	First principal component
P-3C	-1.65
E-3	-0.95
F-5E	-0.79
F-18	0.10
F-15	0.47
F-14	2.81

TABLE E-3

PRINCIPAL COMPONENTS ANALYSIS
(six observations and three variables--quality for year six)

Simple statistics

	MFHBF6	MMHFH6	ANBMR6
Mean	2.35	6.98	3.92
Standard deviation	1.01	5.19	4.47

Correlations

	MFHBF6	MMHFH6	ANBMR6
MFHBF6	1.00	-0.72	-0.44
MMHFH6	-0.72	1.00	0.93
ANBMR6	-0.44	0.93	1.00

	Eigenvalue	Difference	Proportion	Cumulative
First principal component	2.41	1.83	0.80	0.80
Second principal component	0.58	0.57	0.19	0.99
Third principal component	0.01		0.01	1.00

Coefficients

	First principal component	Second principal component	Third principal component
MFHBF6	-0.51	0.81	0.30
MMHFH6	0.64	0.12	0.76
ANBMR6	0.58	0.57	-0.58

Aircraft	First principal component
F-5E	-1.37
P-3C	-0.75
F-18	-0.59
E-3	-0.36
F-15	0.06
F-14	3.02

APPENDIX F

EXCURSIONS ON THE STATISTICAL ANALYSIS OF THE RELATION BETWEEN SE INVESTMENTS OVER TIME AND CHANGES IN QUALITY FOR RELATED TIME PERIODS

APPENDIX F

EXCURSIONS ON THE STATISTICAL ANALYSIS OF THE RELATION BETWEEN SE INVESTMENTS OVER TIME AND CHANGES IN QUALITY FOR RELATED TIME PERIODS

Although no correlation was apparent between overall SE usage and "quality," a modestly statistically significant relation between SE investments[1] over time and changes in quality for related time periods was observed. The following text and tables present the regression analyses supporting this conclusion.

Only six of the aircraft in the sample (F-14, F-15, F-18, F-5E, E-3, and P3-C) had data available for both quality and SE usage in the first few operating years; thus the analysis was limited to just those six aircraft. In order to enlarge the data set, a pooled sample of those six aircraft over two time periods was created. A simple *F*-test suggested that the data sets from those two time periods were from the same population, so the data could be pooled to create a set of 12 observations.

Although the *F*-test indicated that, taken as a whole, the two data sets are not statistically different, individual coefficients may differ based on a T-test. (The *F*-test and *T*-test sometimes give different results.) To examine that possibility, the three basic variables (*Delta SE*, *SE - first year*, and *NEW*) were entered in a regression equation together with a binary variable (*P*) equal to 1 for the first period and 0 for the second period. In addition, each basic variable was entered multiplied by the period 1 binary variable. Table F-1 shows the raw data and table F-2 the regression results.

The variables formed as a product using the period 1 binary variable (such as $P(SE_1)$) are the ones relevant for testing for differences between the two data sets. For instance, the coefficient on *P*(*NEW*) estimates the *difference* between the coefficient on *NEW* in the period 1 data set and the coefficient on *NEW* in the period 2 data set. Similarly, the *T* value on *P*(*NEW*) is the relevant one for testing the significance of this difference. Table F-3 summarizes (to two digits) the coefficients and *T* values relevant for analyzing the differences between the two periods.

---

1. SE investments are the appropriate SE usage values for the given time period adjusted for SE in the initial year and aircraft status (i.e., wholly new aircraft versus model change aircraft).

TABLE F-1

VARIABLES

Aircraft	Period	*Delta Q*	*Delta SE*	*NEW*	SE_1	*P*
P-3C	1	-0.26	1.19	0	0.98	1
F-5E	1	-0.70	0.93	0	0.61	1
E-3	1	0.70	0.97	1	1.06	1
F-18	1	0.40	1.18	1	1.52	1
F-15	1	0.53	0.89	1	1.04	1
F-14	1	-0.66	0.96	1	1.37	1
P-3C	2	-0.90	1.02	0	0.98	0
F-5E	2	0.58	1.10	0	0.61	0
E-3	2	-0.59	0.92	1	1.06	0
F-18	2	0.69	1.07	1	1.52	0
F-15	2	0.41	1.04	1	1.04	0
F-14	2	-0.21	0.89	1	1.37	0

Period = time period
Delta Q = change in quality for time period
Delta SE = actual SE divided by "target" SE for time period
NEW = 1 for new aircraft; 0 for model change
SE_1 = SE usage for first year
P = dummy variable for distinguishing time periods (1 = time period 1; 0 = time period 2)
P(*Delta SE*) = *P* multiplied by *Delta SE*
P(*NEW*) = *P* multiplied by *NEW*
$P(SE_1)$ = *P* multiplied by SE_1

TABLE F-2

ANALYSIS OF VARIANCE--DEPENDENT VARIABLE *DELTA Q*

Source	DF	Sum of squares	Mean square	*F* value	Prob > *F*
Model	7	3.45	0.49	3.01	.15
Error	4	0.65	0.16		
Corr. total	11	4.11			
Root MSE		0.40	R-square	0.84	
Dep mean		0.00	Adj R-sq	0.56	

PARAMETER ESTIMATES

Variable	DF	Parameter estimate	Standard error	*T* for HO: parameter = 0	Prob > |*T*|
Intercept	1	-7.88	2.75	-2.87	.05
SE_1	1	-0.28	0.83	-0.34	.75
NEW	1	0.96	0.55	1.76	.15
Delta SE	1	7.50	2.48	3.02	.04
$P(SE_1)$	1	-4.13	1.91	-2.17	.10
P(NEW)	1	2.21	1.14	1.94	.12
P(Delta SE)	1	0.04	3.84	0.01	.99
P	1	2.92	3.43	0.85	.44

TABLE F-3

COEFFICIENTS RELEVANT FOR TESTING FOR DIFFERENCES BETWEEN SAMPLES

Variable	Coefficient	*T* value	*T* prob
$P(SE_1)$	-4.13	-2.17	.10
P(NEW)	2.21	1.94	.12
P(Delta SE)	0.04	0.01	.99
P	2.92	0.85	.44

The coefficient on $P(SE_1)$ of -4.13 means that in data set 1, the coefficient on SE_1 differs from the corresponding coefficient in data set 2 by -4.13. The T value on that difference (-2.17) is significant at the 10-percent level, though not at the 5-percent level. The interpretation of the coefficients in table F-3 as showing differences between the data sets can be confirmed by looking ahead to tables F-4 and F-5, which show the regressions separately for the two data sets. Similarly, the coefficient on *P(NEW)* suggests that the coefficient on *NEW* in period 1 is 2.21 greater than that in period 2. From the T value (1.94) it can be concluded that the difference is almost significant at the 10-percent level.

The tiny coefficient and T value on *P(Delta SE)* indicate that the coefficients on *Delta SE* are virtually identical in the two data sets. Similarly, the insignificance of the coefficient on P suggests that the intercepts in the two data sets are significantly different.

In sum, table F-3 indicates that in the two data sets the coefficients of *Delta SE* are very similar. The coefficients on *NEW* and SE_1 are quite different. The estimated differences run in the same direction as the effects in period 1. Hence, the differences suggest a diminished effect of SE_1 and *NEW* during the second period. The differences are, perhaps, even more apparent in the separate regressions for the two periods (tables F-4 and F-5).

TABLE F-4

ANALYSIS OF VARIANCE--RESULTS FOR FIRST PERIOD
(Dependent variable, *DIF42*)

Source	DF	Sum of squares	Mean square	F value	Prob > F
Model	3	1.85	0.62	17.37	.05
Error	2	0.07	0.04		
Corr. total	5	1.92			
Root MSE		0.19	R-square	0.96	
Dep Mean		0.00	Adj R-sq	0.91	

PARAMETER ESTIMATES

Variable	DF	Parameter estimate	Standard error	T for H0: parameter = 0	Prob > $\|T\|$
Intercept	1	-4.96	0.95	-5.20	.04
SE_{2-3}	1	7.54	1.37	5.52	.03
NEW	1	3.17	0.46	6.83	.02
SE_1	1	-4.42	0.80	-5.52	.03

TABLE F-5

ANALYSIS OF VARIANCE--RESULTS FOR SECOND PERIOD
(Dependent variable, *DIF64*)

Source	DF	Sum of squares	Mean square	F value	Prob > F
Model	3	1.60	0.53	1.83	.37
Error	2	0.58	0.29		
Corr. total	5	2.18			
Root MSE		0.54	R-square	0.96	
Dep Mean		0.00	Adj R-sq	0.91	

PARAMETER ESTIMATES

Variable	DF	Parameter estimate	Standard error	T for H0: parameter = 0	Prob > $\|T\|$
Intercept	1	-7.88	3.67	-2.15	.16
SE_{4-5}	1	7.50	3.31	2.26	.15
NEW	1	0.96	0.73	1.32	.32
SE_1	1	-0.28	1.11	-0.26	.82

Table F-6 shows the basic regression applied to a single quality improvement increment from year two to year six. Thus, it provides information similar to that from the pooled sample. The coefficient on *Delta SE* (SE_{2-5}) in this regression is the same as that displayed in table 8 of the main text.

TABLE F-6

ANALYSIS OF VARIANCE--RESULTS SPANNING TWO PERIODS
(Dependent variable, *DIF62*)

Source	DF	Sum of squares	Mean square	*F* value	Prob > *F*
Model	3	3.33	1.11	2.56	.29
Error	2	0.87	0.43		
Corr. total	5	4.20			
Root MSE		0.66	R-square	0.79	
Dep Mean		0.00	Adj R-sq	0.48	

PARAMETER ESTIMATES

Variable	DF	Parameter estimate	Standard error	*T* for H0: parameter = 0	Prob > |*T*|
Intercept	1	-9.47	4.70	-2.01	.18
SE_{2-5}	1	11.60	5.53	2.10	.17
NEW	1	3.63	1.36	2.67	.12
SE_1	1	-4.30	2.10	-2.04	.18